



7N-02
197231
23P

TECHNICAL NOTE

D-170

LIFT AND DRAG CHARACTERISTICS AT SUBSONIC SPEEDS AND AT
A MACH NUMBER OF 1.9 OF A LIFTING CIRCULAR CYLINDER

WITH A FINENESS RATIO OF 10

By Vernard E. Lockwood and Linwood W. McKinney

Langley Research Center
Langley Field, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON

December 1959

(NASA-TN-D-170) LIFT AND DRAG
CHARACTERISTICS AT SUBSONIC SPEEDS AND AT A
MACH NUMBER OF 1.9 OF A LIFTING CIRCULAR
CYLINDER WITH A FINENESS RATIO OF 10 (NASA)
23 p

N89-76576

Unclas
00/02 0197231

13

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-170

LIFT AND DRAG CHARACTERISTICS AT SUBSONIC SPEEDS AND AT

A MACH NUMBER OF 1.9 OF A LIFTING CIRCULAR CYLINDER

WITH A FINENESS RATIO OF 10

By Vernard E. Lockwood and Linwood W. McKinney

SUMMARY

L
5
9
0

An exploratory wind-tunnel investigation has been made on a circular cylinder at subsonic speeds and at a Mach number M of 1.9 to determine the feasibility of using small flaps to develop lift for possible reentry application. Several full-span flaps attached normal to the lower surface of the cylinder and varying in chord from 0.004 to 0.300 diameter were used as lift-generating devices. Most of the tests were made with flaps located at the 50-percent-chord station although a few tests were made with the chordwise location as one of the parameters. The investigation was made on a cylinder with a fineness ratio of 10 over a Mach number range from 0.07 to 0.80 and at $M = 1.9$. The investigation covered a range of Reynolds number from 355,000 to 1,600,000.

The results indicated that lift could be generated throughout the range of Mach numbers of the investigation. For flaps located at the 50-percent-chord station, increases of flap size up to 20 percent of the cylinder diameter gave increases of lift coefficient, a maximum of 1.63 being obtained at a Mach number of 0.3. The lift effectiveness of all flaps decreased rapidly above a Mach number of about 0.3 but was positive for all Mach numbers of the investigation when the flap chord was 5 percent or greater. The ineffectiveness of small flaps could be slightly improved at higher subsonic Mach numbers by locating them near the leading edge. The drag of a lifting circular cylinder increases rapidly at subcritical Mach numbers as the flap chord is increased, but at a Mach number of 1.9 the drag of the cylinder with the 10-percent-chord flap was only about 7 percent higher than that of the nonlifting cylinder. For Mach numbers up to 0.5 the lift-drag ratios of the cylinder with flaps attached at the 50-percent-chord station were relatively independent of flap size for values between 5 and 20 percent of the chord. For a flap chord of 10 percent the lift-drag ratio decreased from a high of about 2.2 at a Mach number of 0.3 to a low of about 0.2 at a Mach number of 1.9.

INTRODUCTION

The high drag of a right circular cylinder with axis normal to the relative wind, coupled with a means of developing lift, suggests the idea of using the rocket casing of a satellite booster as a reentry vehicle. The possibility of achieving sizable lift coefficients on circular cylinders was indicated in the course of an investigation to determine the aerodynamic characteristics of cylinders having tangential blowing to generate lift. In this investigation it was found that the spanwise slots from which the air was ejected could, without any blowing, produce crosswind forces of considerable magnitude. With this in mind, an investigation was made on a circular cylinder (normal to the wind) utilizing full-span flaps of varying chords located on the lower surface as lift-generating devices. The purpose, therefore, of this investigation was to determine the effect of flap size and chordwise location on the lift and drag characteristics of a cylinder through a range of Mach numbers. No means was provided for determining the pitching moments associated with the flaps.

In this investigation several full-span flaps attached to the lower surface of the cylinder and varying in chord from 0.004 to 0.300 diameter were used as lift-generating devices. Most of the tests were made with flaps located at the 50-percent-chord station although a few tests were made with the chordwise location as one of the parameters. This series of tests was made on a 5-inch-diameter cylinder over a Mach number range from 0.20 to 0.80 and a Reynolds number range from 570,000 to 1,480,000. A smaller model was tested in one of the supersonic facilities at a Mach number of 1.9. The corresponding Reynolds number was about 604,000. Some additional tests were made on a larger cylinder without flaps at sub-critical Mach numbers to determine the drag characteristics of a nonlifting cylinder for a Reynolds number range from 355,000 to 1,600,000 in order to isolate Mach and Reynolds number effects. All tests were made on a cylinder with a fineness ratio of 10.

SYMBOLS

The data are presented with respect to the wind axes as indicated in figure 1.

C_L lift coefficient, $\frac{2(\text{Semispan lift})}{qS}$

C_D drag coefficient, $\frac{2(\text{Semispan drag})}{qS}$

S	twice projected area of cylinder semispan, sq ft
q	free-stream dynamic pressure, $\frac{\rho V^2}{2}$, lb/sq ft
ρ	free-stream density, slugs/cu ft
V	free-stream velocity, ft/sec
R	Reynolds number based on cylinder diameter
L	lift
D	drag
M	Mach number
δ	flap angular position relative to wind, positive from trailing edge down, deg (fig. 2)
c	flap chord, in.
d	cylinder diameter, in.

MODEL AND APPARATUS

In this investigation three cylinders and three facilities were used. For the part of the investigation dealing with the generation of lift at subsonic speeds a 5-inch cylinder was tested in the high-speed 7- by 10-foot tunnel and for the tests at a Mach number of 1.90 a 0.450-inch cylinder was used in one of the 9-inch blowdown jets of the Gas Dynamics Branch. In the case of the nonlifting cylinder, where drag determination was the important consideration, an 8.34-inch cylinder was used; these tests were made in the 300-MPH 7- by 10-foot tunnel. All cylinders were semispan models having an equivalent fineness ratio of 10 (assuming full reflection).

The 5-inch cylinder used in the lift investigation at subsonic speeds was mounted from the reflection-plane setup of the high-speed 7- by 10-foot tunnel. A diagram of this setup is given in figure 1. The model was equipped with a 10-inch-diameter end plate at the inboard end to prevent spanwise flow across the model. The reflection plane was recessed for the end plate in order to give a flush mounting when completely assembled. The cylinder was attached to a 3-inch thick-wall steel tube which was supported between the tunnel wall and the reflection plane by a bearing. The

bearing was in turn supported by electrical load cells, the output of which was recorded on the standard tunnel readout system. The opposite end of the steel tube was rigidly supported about 80 inches from the inner bearing by a split clamp which allowed the cylinder to be rotated to a desired position.

A number of flaps varying in chord were attached to the 5-inch cylinder as shown in figure 2(a) to generate lift. Four of these lift-generating devices ($c/d = 0.013, 0.050, 0.200, \text{ and } 0.300$) were made of aluminum angle and attached by screws to the cylinder. One flap having a chord of 10 percent ($c/d = 0.100$) had a wedge-shaped profile, as shown in figure 2(a), with the wedge facing upstream. The smallest flap ($c/d = 0.004$) consisted of 0.020-inch sand grains cemented to the cylinder in a strip 0.12 inch wide. All flaps covered the complete span of the cylinder except for 0.25 inch at the outboard end. The test at $M = 1.9$ was made on a cylinder with a diameter of 0.450 inch and a length of 2.25 inches. The flap used with this model was a thin sharp-edge metal inset in the cylinder projecting to a value of c/d of 0.10. (See fig. 2(b).)

Most of the tests on the 5-inch cylinder were made with the flap located at the midchord point ($\delta = 90^\circ$, fig. 2(a)). A few flap chords were investigated, however, with their location varied from $\delta = 0^\circ$ to $\delta = 135^\circ$. The range of flap location for the $M = 1.9$ tests was somewhat different, varying from 86° to 153° .

The system was calibrated with the loads applied at the midsemispan of the cylinder. Any discrepancy between the midsemispan and the actual center-of-pressure location would introduce small errors in the measured forces. However, an additional calibration indicated that a 5-percent variance in the center of pressure would introduce only a 2-percent error in measured forces.

TESTS

The following table gives the range of tests and the facilities used during the present investigation. The variation of Reynolds number with Mach number is shown in figure 3.

Cylinder diam., in.	Mach number range	Reynolds number range	Tunnel facility
5.000 8.340 .450	0.20 to 0.80 .07 to .36 1.9	570,000 to 1,480,000 355,000 to 1,600,000 604,000	High-speed 7- by 10-foot 300-MPH 7- by 10-foot Blowdown jet of the Langley Gas Dynamics Branch

The Reynolds number is based on cylinder diameter.

In the subsonic speed range the lift investigation was made by using a reflection plane attached to the side of the tunnel so that the model would be relatively clear of tunnel-wall boundary-layer effects. The reflection plane used in the high-speed 7- by 10-foot tunnel investigation generates spanwise velocity gradients which at $M = 0.8$ amount to about 3 percent over the length of the model. For this investigation the average velocity along the model span was used in computing the data.

The tests at $M = 1.90$ were conducted in one of the 9-inch blow-down jets of the Gas Dynamics Branch. The jet is designed so that semi-span models can be mounted from the floor of the 9-inch-wide 6-inch-high section. A boundary-layer scoop ahead of the model is provided to remove a portion of the low-energy air.

The 8.34-inch-diameter cylinder which was used for low-speed drag determination was tested in the Langley 300-MPH 7- by 10-foot tunnel. Air-leakage effects around the end of the cylinder were minimized by the addition of a small end plate near the tunnel ceiling. The results of two-dimensional tests on this cylinder are published in reference 1.

RESULTS AND DISCUSSION

Lift

The results presented in figures 4 to 9 indicate that considerable lift can be generated on a cylinder at subsonic speeds by the addition of flaps on the bottom surface. The investigation indicated, as might be expected, that the lift is a function of flap location, chord, and Mach number. The initial tests (fig. 4) with a flap chord of 10 percent of the diameter ($c/d = 0.10$) showed that the lift coefficient was dependent on flap location over a range of δ from 35° to 140° and that the maximum lift coefficient occurred at $\delta = 90^\circ$, which corresponds to the 50-percent-chord line. The maximum value of lift coefficient obtained

with a 10-percent-chord flap was 1.43. A further increase in flap chord to 20 percent resulted in increases in the maximum lift coefficient to 1.63.

The Mach number effects on lift are large, as indicated in figure 5. This result might be expected, however, because of the large thickness ratio involved. With the 10-percent-chord flap the lift decreased from a value of 1.43 at $M = 0.3$ to a value of about 0.5 at $M = 0.7$. No data are available between $M = 0.8$ and $M = 1.9$ to indicate the variation, but at $M = 1.9$ the 10-percent flap gave a lift coefficient of only 0.32. The Mach number effects at subsonic speeds are better illustrated in figure 6, where the results are shown for several flaps located at the 50-percent-chord line. In general, the lift effectiveness decreased rapidly above $M = 0.3$. For flaps having chords of 0.4 to 1.3 percent of the diameter this decrease in lift is enough to make the spoiler ineffective at $M = 0.72$. The loss of lift with Mach number may be the result of movement of the natural separation point on the cylinder to a location far enough forward to leave these very small flaps in a separated region. Whatever the cause, some effectiveness may be restored by locating the flap farther forward, as shown in figures 7 and 8. For the 1.3-percent-chord flap the angular displacement necessary for maximum positive lift is about 15° ($\delta = 105^\circ$) whereas with the 0.4-percent-chord flap it is considerably farther forward ($\delta = 140^\circ$).

L
5
9
0

For the summary of lift characteristics presented in figure 9 the data for the 50-percent-chord location ($\delta = 90^\circ$) has been used. As stated above, these data show that the flaps are very effective in producing lift at the lower subsonic speeds. The actual lift variation with flap size can be given approximately by the equations

$C_L = 2.25(c/d)^{1/5}$ for $M = 0.3$ and $C_L = 1.55(c/d)^{1/5}$ for $M = 0.5$. These equations are valid for a $c/d \geq 0.013$. At the higher subsonic Mach numbers ($M = 0.75$) the lift effectiveness is materially reduced and flap chords of $c/d \leq 0.013$ are completely ineffective.

Drag

Nonlifting cylinders.— A comparison of the drag characteristics of the 5-inch cylinder with those of an 8.34-inch cylinder is given in figure 10 for the range of Reynolds numbers and subsonic Mach numbers of this investigation. Also included in this figure are results obtained two dimensionally from a previous investigation of the large cylinder (ref. 1). A cursory examination of the figure indicates large variations in the drag coefficient with Reynolds number, Mach number, and fineness ratio, and some differences probably resulting from different test techniques.

The tests made on the larger cylinder to provide drag data at high Reynolds numbers below the critical Mach number gave greater values of drag coefficient than the tests on the small cylinder (see bottom portion of fig. 10). This difference, which amounts to a C_D increment of about 0.04 at a given Reynolds number, is probably the result of balance sensitivities. Because of the larger forces and greater balance sensitivity the results for the 8.34-inch cylinder should be considered most reliable at Mach numbers below 0.4.

In the critical Reynolds number range ($R = 400,000$) the data of figure 10 indicate only minor differences between the drag coefficients for the two-dimensional cylinder of reference 1 and those for the large cylinder with fineness ratio of 10. Also shown in figure 10 by means of solid symbols are the drag coefficients at a Reynolds number of 88,000 obtained from reference 2 for both cylinder configurations. At this Reynolds number very large reductions in drag coefficients are indicated for the finite-length cylinder. In the range of Reynolds numbers above the critical values and below the critical Mach numbers, the large cylinder with fineness ratio of 10 has drag coefficients materially less than the two-dimensional values. The drag coefficient increases in a more or less steady manner from a low of about 0.25 at $R = 400,000$ to a high of 0.45 at $R = 1,600,000$. The two-dimensional drag coefficients likewise show an increase with Reynolds number.

The data from the 5-inch cylinder show the expected drag-rise increase with Mach number (upper part of fig. 10) that occurs at subsonic speeds. This increase, which occurs at about $M = 0.45$, is later than would be expected from two-dimensional data at $M = 0.4$ in reference 3. This delay in drag-rise Mach number probably results from a reduction in the velocity over the cylinder because of the end relieving effect. After the critical Mach number is reached the drag coefficient rises to a maximum of 1.38 at $M = 0.7$ and decreases to a value of 1.05 at $M = 0.8$. The two-dimensional data of reference 3 also show initial peaks in this Mach number range. For the most part the higher drag values obtained for the larger cylinder at a given Mach number are associated with the higher Reynolds number.

Lifting cylinder.- The effect of flap chord on the drag characteristics of a cylinder appears to be unpredictable. In figure 6 the drag of the cylinder increases rapidly at subcritical Mach numbers as the flap chord is increased, but in the range of Mach numbers near 0.7 two of the flaps actually reduce the drag of the cylinder. For example, at $M = 0.7$ the drag coefficient is reduced from a high of 1.38 for the plain cylinder to a low of about 1.05 for $c/d = 0.10$ at $\delta = 90^\circ$. This same flap at $M = 0.2$ gave about a 230-percent increase in drag. At $M = 1.9$ (fig. 5) the same size flap increased the drag only 7 percent based on the value $C_D = 1.48$ of reference 3.

Lift-Drag Ratio

The maximum values of L/D were obtained in the low-speed range ($M = 0.3$) and were relatively constant at about 2.2 for a range of flap chords from 5 to 20 percent of the cylinder diameter, as shown in figure 9. At $M = 0.5$ the lift-drag ratios were approximately half the values at $M = 0.3$. At a Mach number of 0.75 the small flaps ($c/d = 0.004$) were completely ineffective. Above $c/d = 0.013$, however, L/D increased, reaching a maximum value of about 0.5 at $c/d = 0.20$. The value of L/D at $M = 1.9$ was only about 0.20 for $c/d = 0.10$, which is about half of the value at $M = 0.75$.

SUMMARY OF RESULTS

An exploratory wind-tunnel investigation in the range of Mach numbers from 0.07 to 0.8 and at $M = 1.9$ has been made to determine the lift and drag characteristics of a lifting circular cylinder with a fineness ratio of 10. Full-span flaps varying in chord from 0.004 to 0.300 cylinder diameters and located on the bottom surface (50-percent-chord station) were used as lift-generating devices. The results are summarized as follows:

1. Increases of flap chord up to 20 percent of the cylinder diameter gave increases of lift coefficient, a maximum of 1.63 being obtained at a Mach number of 0.3.
2. The lift effectiveness of all flaps decreased rapidly above a Mach number of about 0.3 but was positive for all Mach numbers of the investigation with flap chords of 5 percent of the diameter or greater.
3. The lift effectiveness of small flaps could be slightly improved at the higher subsonic Mach numbers by locating them nearer the leading edge.
4. At a Mach number of 1.9 a 10-percent-chord flap gave a lift coefficient of 0.32.
5. The drag of a lifting circular cylinder increases rapidly at subcritical Mach numbers as the flap chord is increased, but in the range of Mach numbers near 0.7 the cylinder with 5- and 10-percent-chord flaps actually had less drag than the plain cylinder.
6. At a Mach number of 1.9 the drag of the cylinder with the 10-percent-chord flap was only about 7 percent higher than that of the nonlifting cylinder.

7. The drag coefficient of the plain cylinder varied from a value which is slightly less than the two-dimensional value to a high of 1.38 at a Mach number of 0.7, which is in the range of Mach numbers where some two-dimensional values have initial peaks.

8. For Mach numbers up to 0.5 the lift-drag ratios were relatively independent of flap size for values between 5 and 20 percent of the chord. For a flap chord of 0.1 diameter the lift-drag ratio decreased from a high of about 2.2 at a Mach number of 0.3 to a low of 0.2 at a Mach number of 1.9.

APPLICATION

A means of developing lift on a circular cylinder has indicated the possibility of controlling the return to earth of satellites having cross sections similar to those of circular cylinders. The concept of recovery involves reorientation of the vehicle so that its major axis is normal to the flight path and the generation of lift. Such a vehicle in a launching attitude is shown in the left-hand part of figure 11. The orbiting configuration is shown in the top right of the figure with the nose cone removed. The vehicle before reentry is reoriented by means of a series of reaction controls so that it is normal to the orbit. In this phase of the operation the boom which supports the aerodynamic control surfaces is rotated into position so as to provide stability and control in the atmosphere. The "reentry" configuration is shown in the center diagram of figure 11. At some time during the return to earth a flap located on the bottom surface is deflected to generate lift. Such a configuration is shown in the lower right-hand corner of figure 11. With the flap deflected an actual glide landing might be accomplished because the lift as well as the lift-drag ratios increase as speeds comparable to landing speeds are approached. It may, however, be desirable to deflect the flap prior to reentry, in which case some measure of trajectory or glide control can be maintained throughout the return trip to earth.

The lifting principle described in the preceding paragraph might also be used in the recovery of expensive cylindrical rocket boosters.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., August 18, 1959.

REFERENCES

1. Polhamus, Edward C.: Effect of Flow Incidence and Reynolds Number on Low-Speed Aerodynamic Characteristics of Several Noncircular Cylinders With Applications to Directional Stability and Spinning. NACA TN 4176, 1958.
2. Wieselsberger, C.: Der Widerstand von Zylindern. *Ergb. Aerod. Versuchsanstalt zu Göttingen, Lfg. II*, R. Oldenbourg (Munich), 1923, pp. 23-28.
3. Gowen, Forrest E., and Perkins, Edward W.: Drag of Circular Cylinders for a Wide Range of Reynolds Numbers and Mach Numbers. NACA TN 2960, 1953.

L
5
9
0

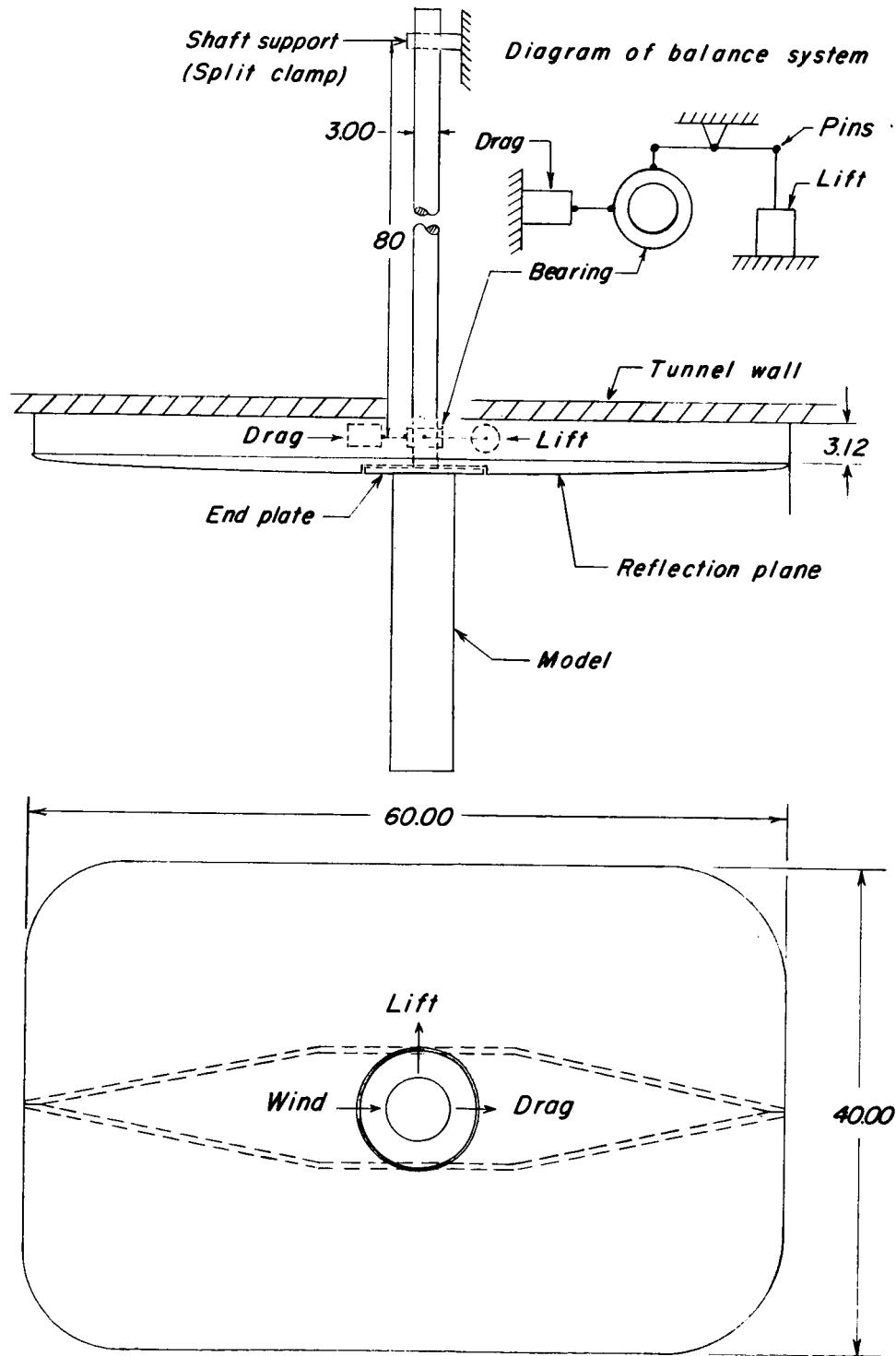
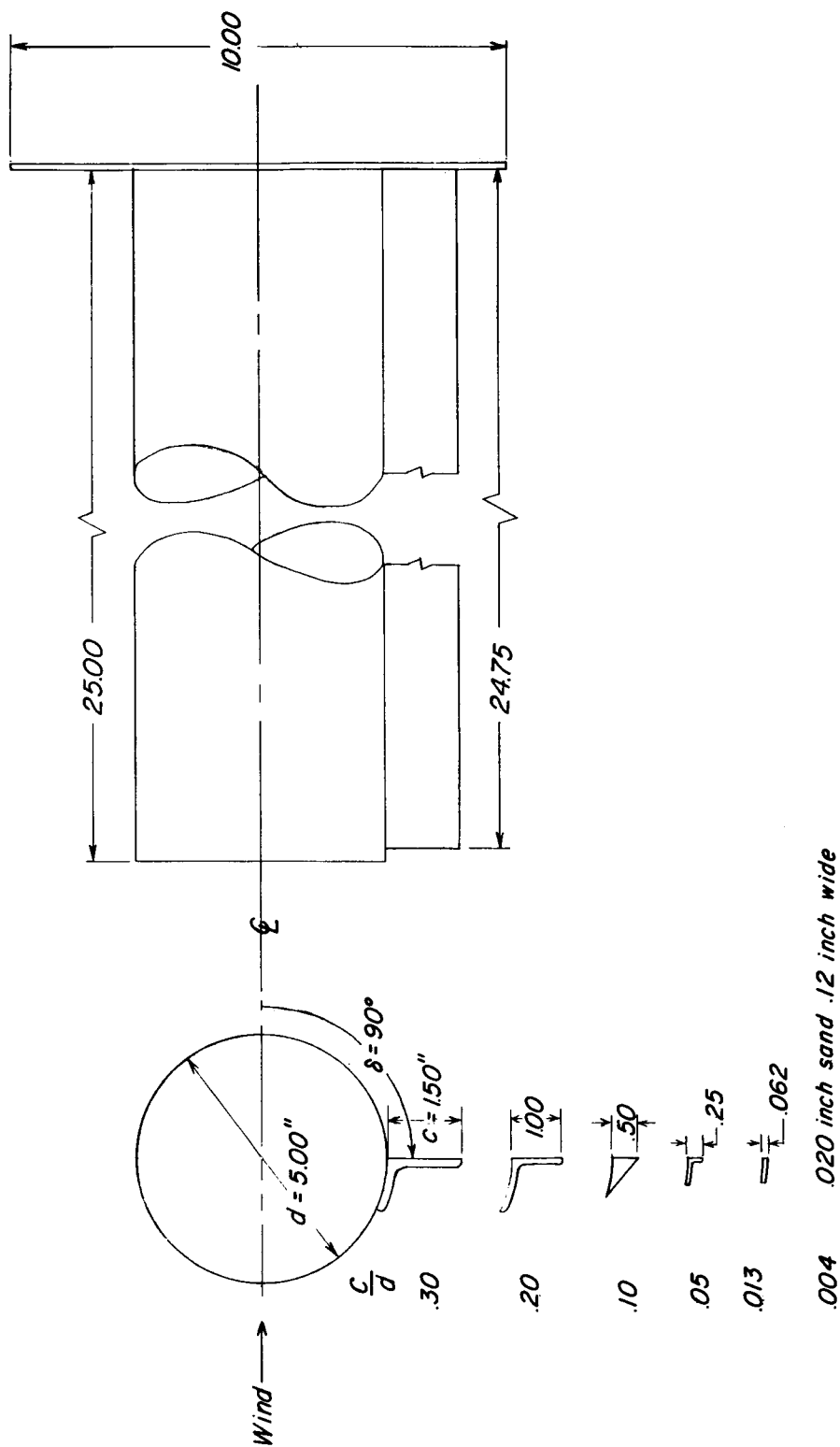
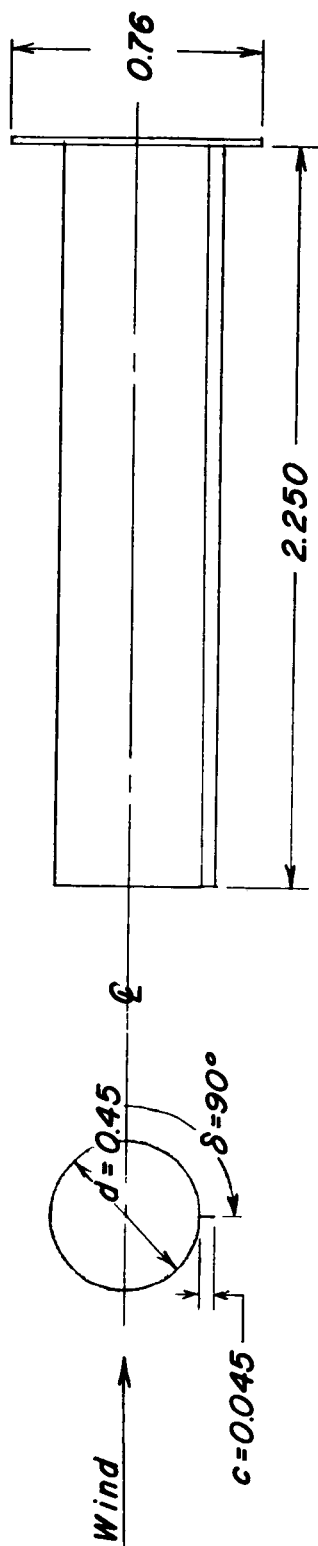


Figure 1.- Reflection-plane setup for 5-inch cylinder.



(a) 5-inch cylinder. Subsonic speeds.

Figure 2.- Flaps used on cylinders in investigation.



(b) 0.45-inch cylinder. $M = 1.90$.

Figure 2.- Concluded.

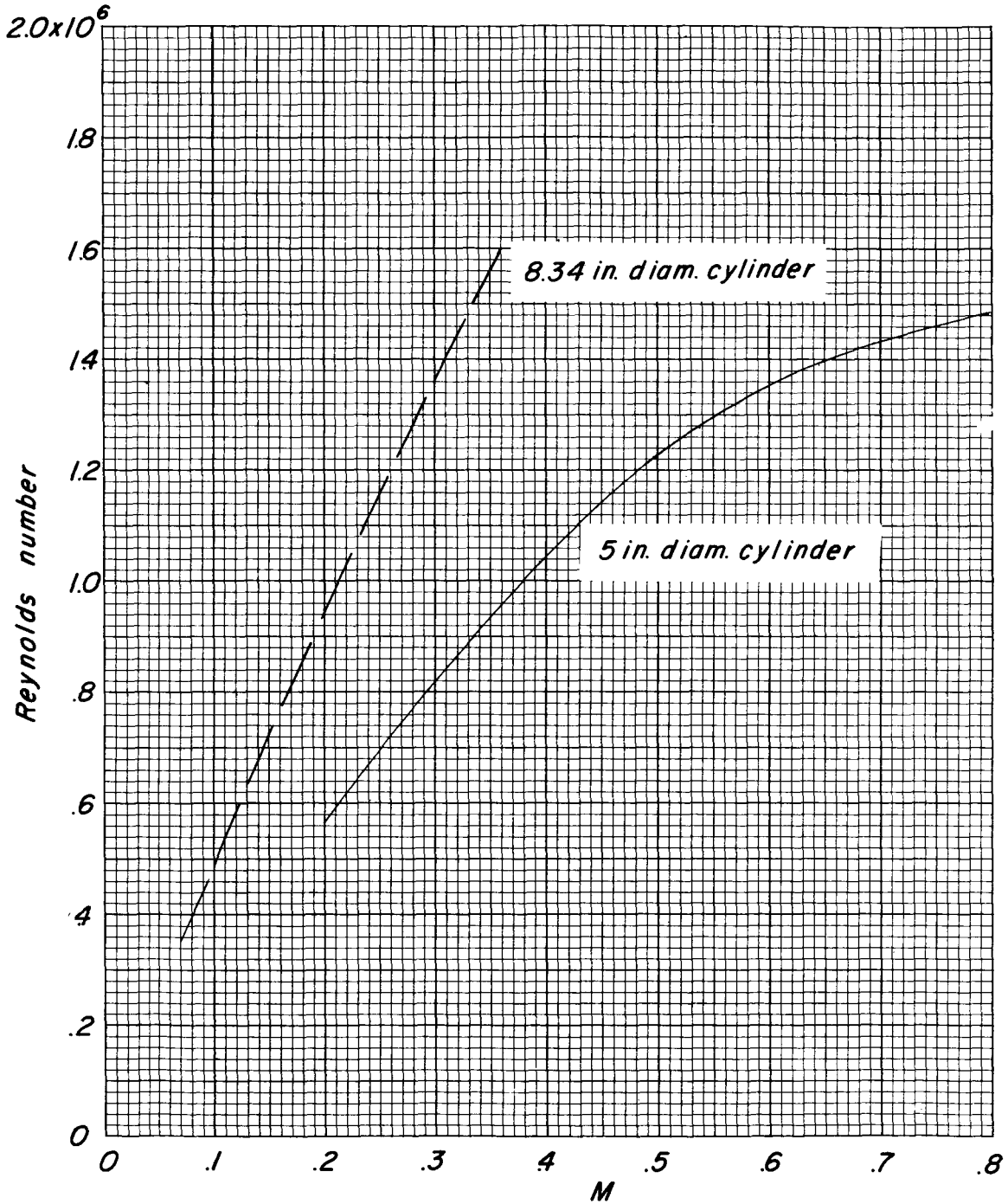


Figure 3.- Variation of Reynolds number with Mach number for the two large cylinders used in the investigation.

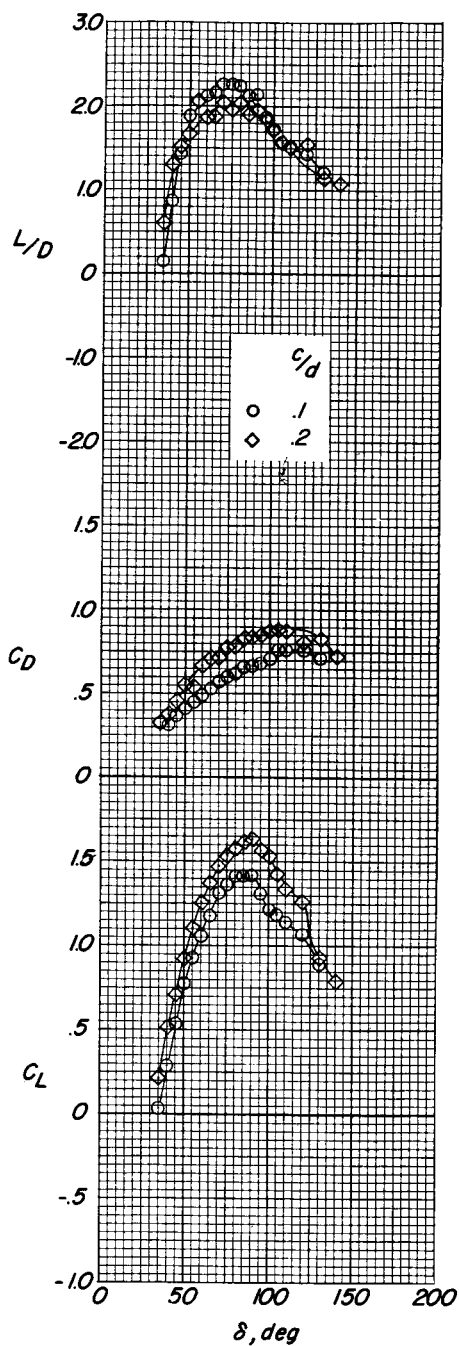


Figure 4.- Effect of flap angular position on the lift and drag characteristics of a cylinder for two values of c/d .
 $M = 0.3$.

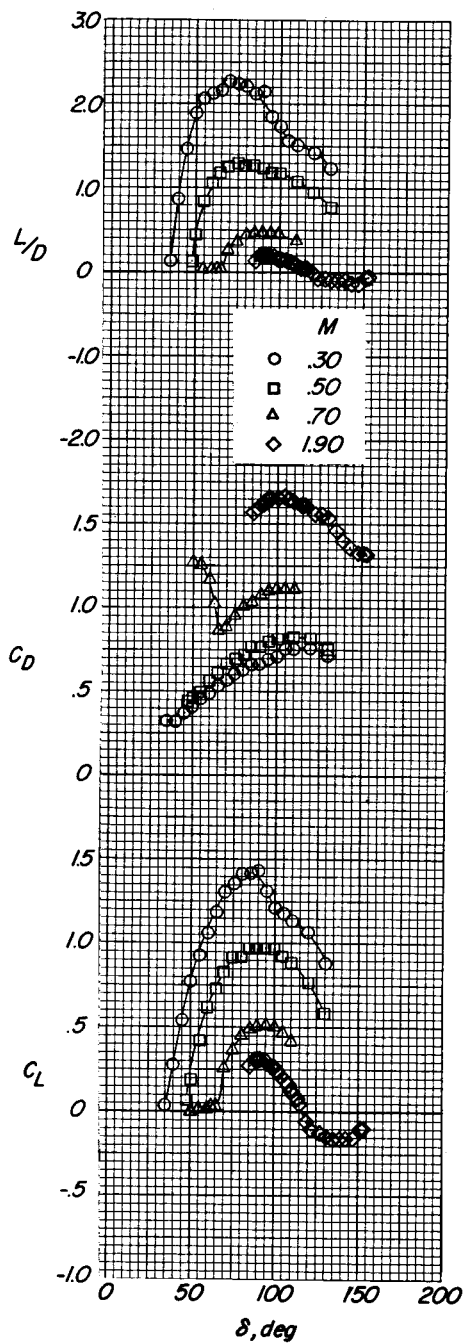


Figure 5.- Effect of flap angular position on the lift and drag characteristics of a cylinder for four Mach numbers.
 $c/d = 0.10$.

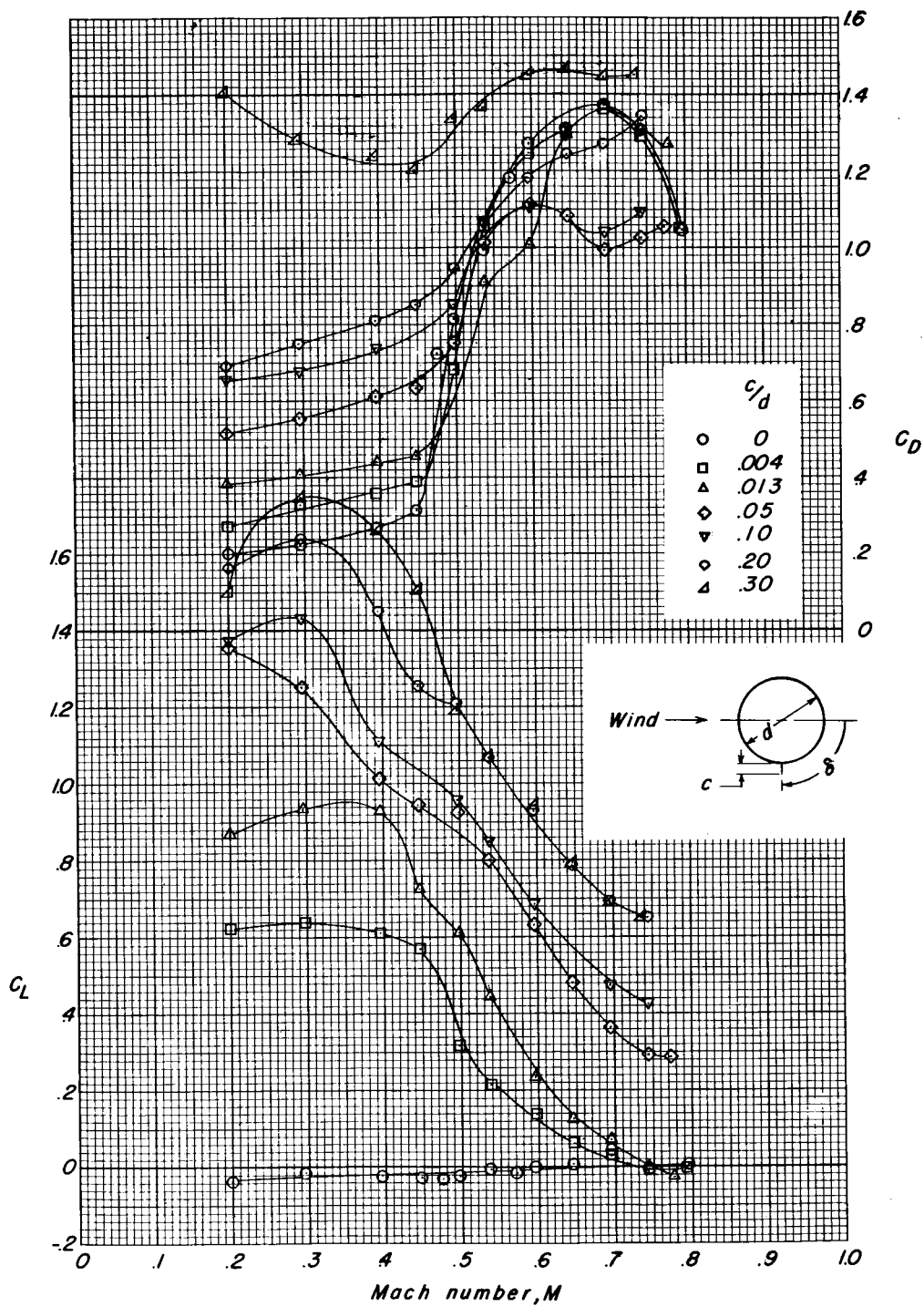


Figure 6.- Effect of flap chord and Mach number on the lift and drag characteristics of a cylinder. $\delta = 90^\circ$.

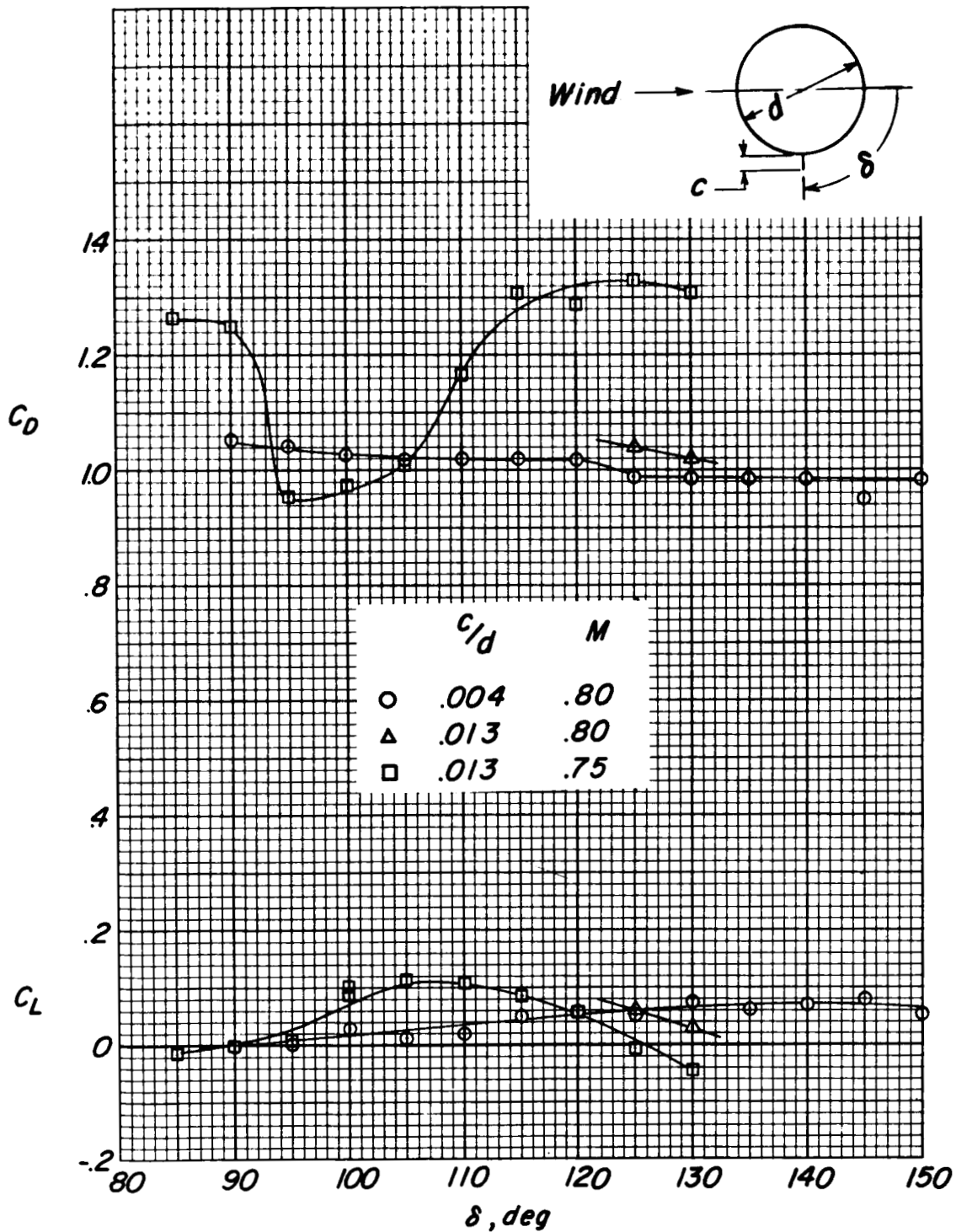


Figure 7.- Effect of flap angular position on the lift and drag characteristics of a cylinder for two values of c/D .

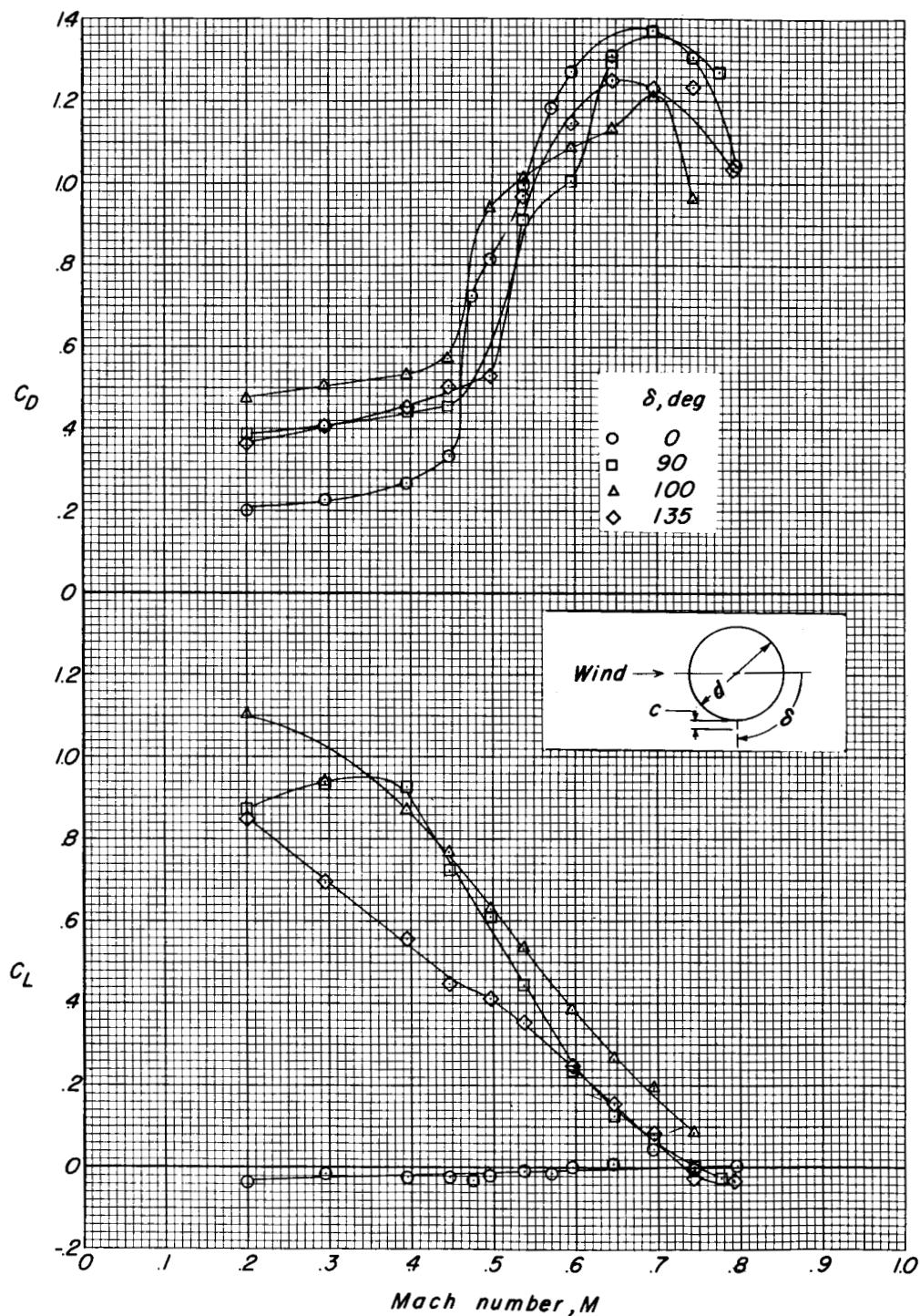


Figure 8.- Effect of flap angular position and Mach number on the lift and drag characteristics of a cylinder. $c/D = 0.013$.

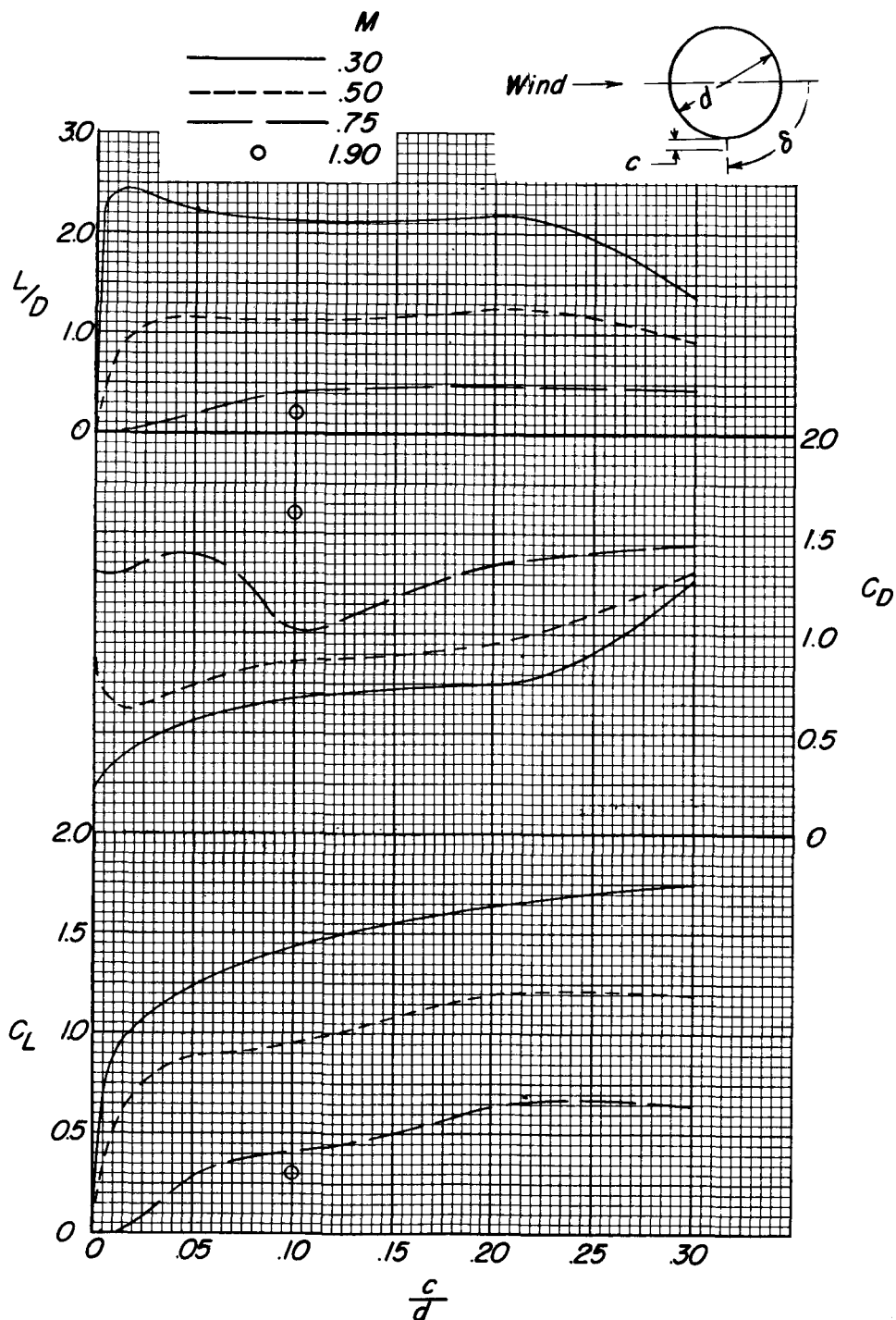


Figure 9.- Summary of the effects of flap chord on the lift and drag characteristics of a circular cylinder. $\delta = 90^\circ$.

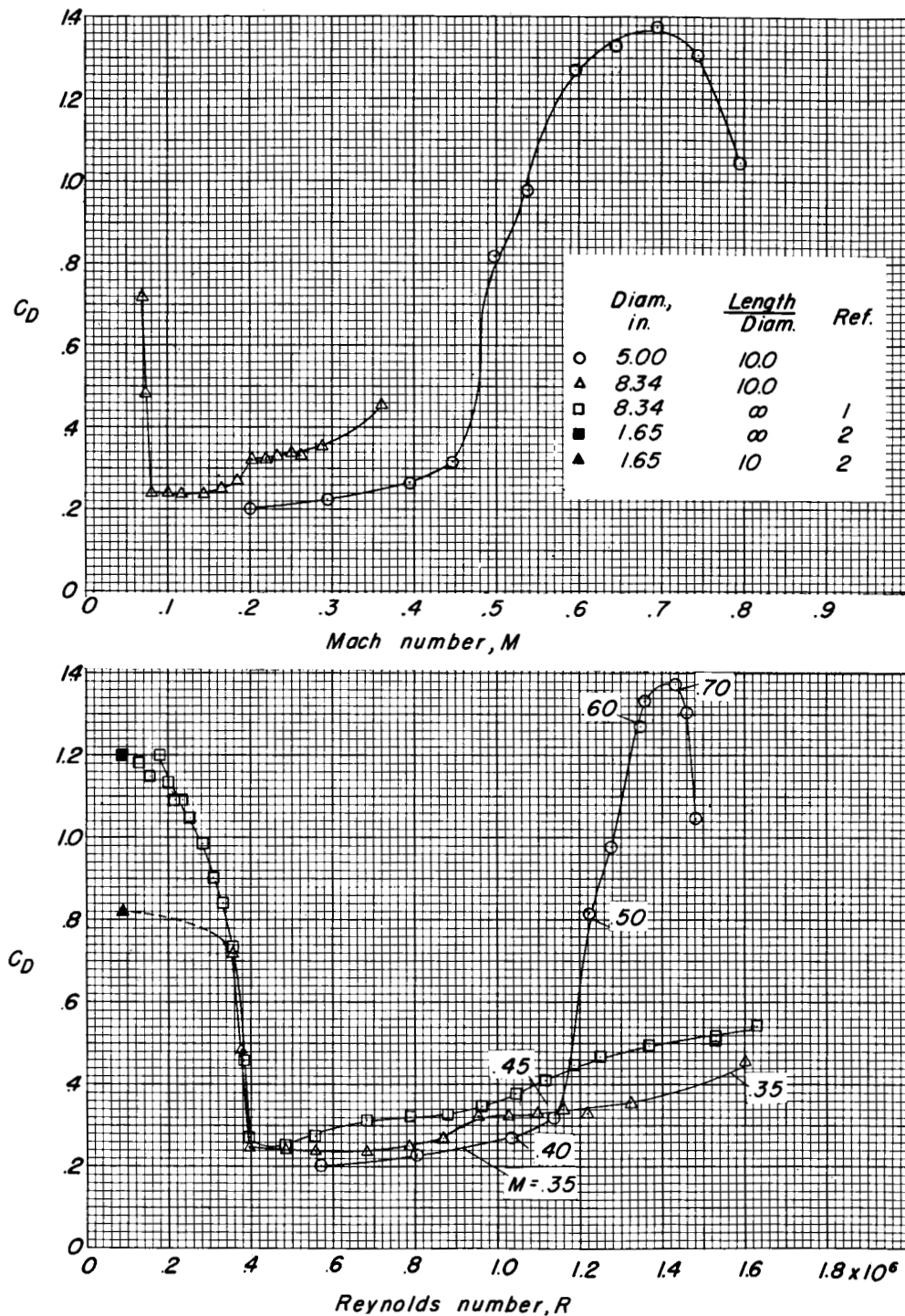


Figure 10.- Variation of drag coefficient with Reynolds and Mach number for the two large cylinders used in the investigation.

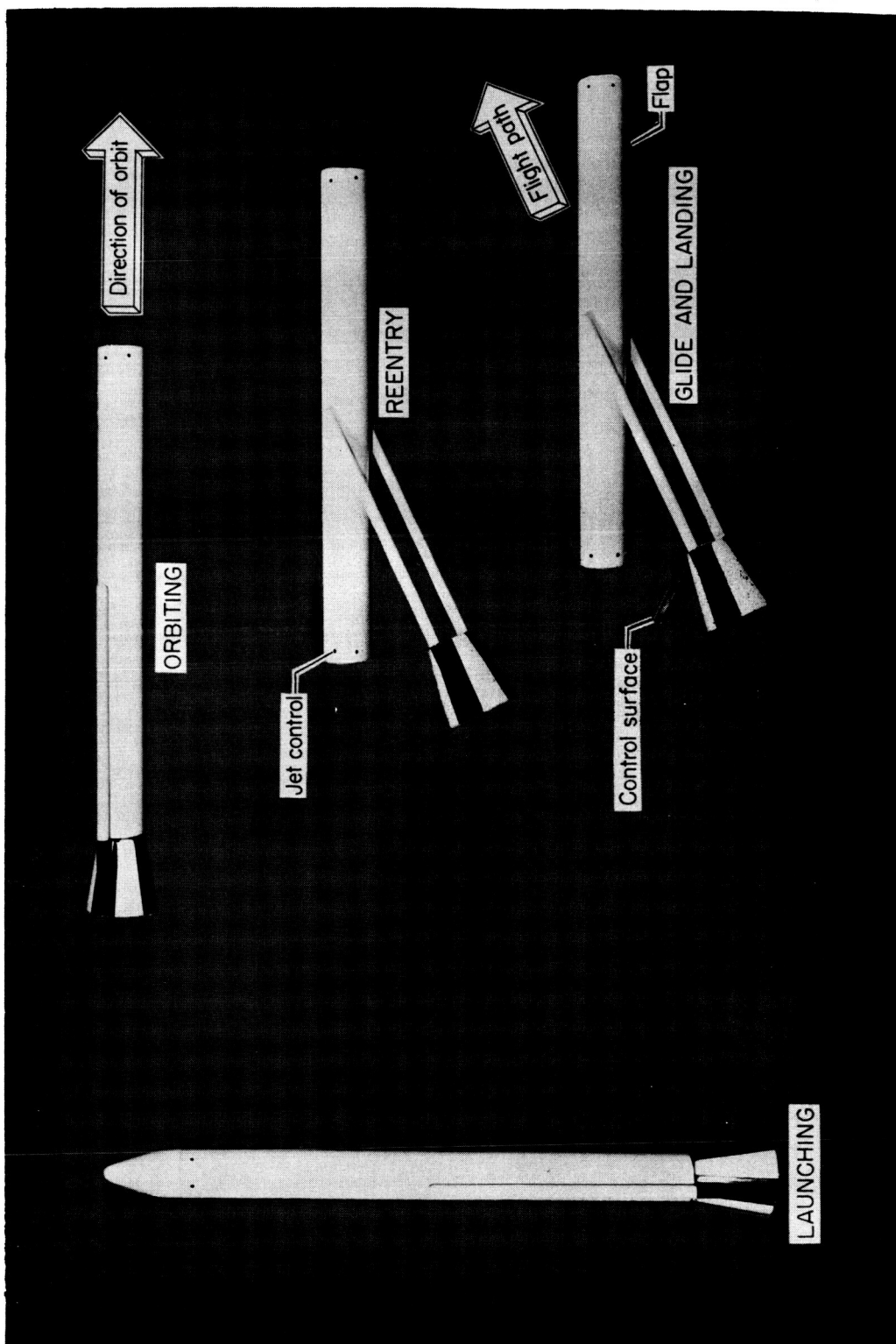


Figure 11.- Illustration of the possible application of the lifting-cylinder technique to the recovery of cylindrical satellites and rocket boosters.